

# Submillimetre detection of the $z = 2.83$ Lyman-break galaxy, Westphal MM8, and implications for SCUBA2

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## ABSTRACT

We present confusion limited submillimetre (submm) observations with the SCUBA camera on the JCMT of the  $z = 2.83$  Lyman-break galaxy (LBG), Westphal-MM8, reaching an  $850\mu\text{m}$  sensitivity even greater than that achieved in the SCUBA map of the Hubble Deep Field region. The detection of MM8 ( $S_{850\mu\text{m}} = 1.98 \pm 0.48 \text{ mJy}$ ), along with the literature submm detections of lensed LBGs, suggest that the LBG population may contribute significantly to the source counts of submm selected galaxies in the 1–2 mJy regime. Additionally, submm-luminous LBGs are a viable progenitor population for the recently discovered *evolved* galaxies at  $z \sim 2 - 2.5$ . These observations represent an important baseline for SCUBA2 observations which will regularly map large regions of the sky to this depth.

**Key words:** Lyman-break Galaxies: starforming; Individual Westphal-MM8

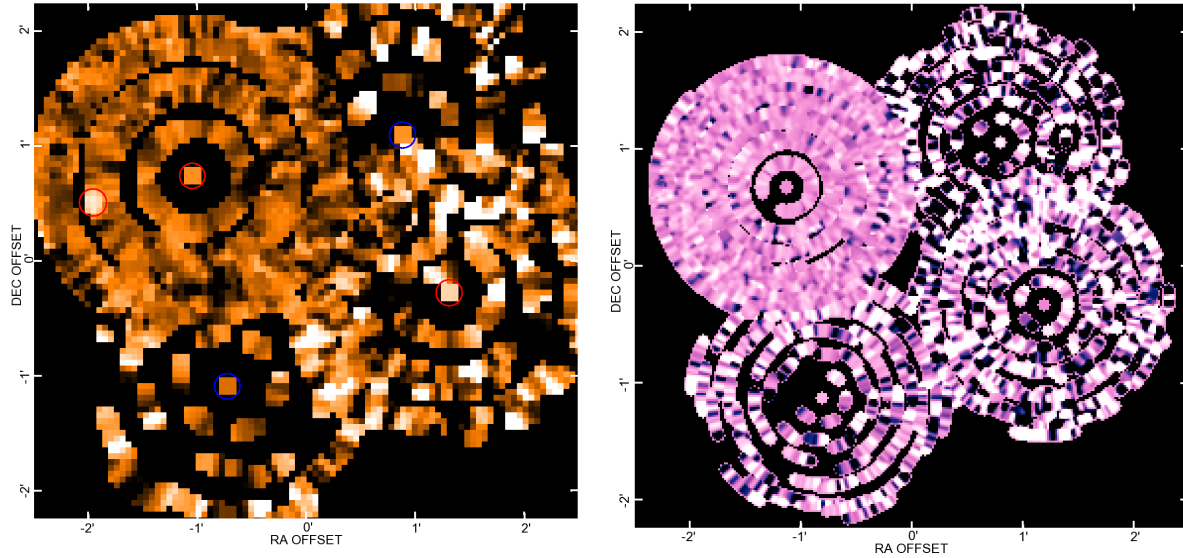
## 1 INTRODUCTION

Lyman-break galaxies (LBGs) represent the largest population of high-redshift ( $z > 3$ ) star forming galaxies yet discovered (Steidel et al. 1999), likely comprising a significant percentage of the far-infrared (FIR) background (Adelberger & Steidel 2000). The dust-corrected star formation rate (SFR) distribution of LBGs,  $n(\text{SFR})$ , shows significant numbers of  $z \sim 3$  galaxies with  $\text{SFR} \gtrsim 100 \text{ M}_{\odot}/\text{yr}$  (representing  $S_{850\mu\text{m}} \sim 1 \text{ mJy}$  depending on adopted dust parameters). However, the search for submm counterparts to LBGs has proved difficult due to uncertainties in the relations used to predict the rest frame far-IR luminosity from the UV, and also photometric errors. Since dusty, submm luminous LBGs would characteristically have their UV continuum highly suppressed due to dust extinction, it is difficult to distinguish between a truly prodigious star former and a less luminous galaxy with an intrinsically low SFR and large photometric errors. The FIR and submm emission from LBGs, their dust content, and their contribution to the FIR background light remains an unsolved puzzle for which major progress can only be expected with the new sensitive instruments and telescopes such as SCUBA-2 and ALMA.

A few highly lensed LBGs have been detected in the submm wavelengths, and represent good test cases for the far-IR properties of  $z = 3$  star forming galaxies (e.g., Smail et al. 2007). However, these objects could suffer from differential lensing of the UV and far-IR components (e.g., Bo-

rys et al. 2004) and may be more difficult to gauge relative to the general population. The sole submm detection of an unlensed LBG thus far has been for the extremely red ( $R - K \sim 5$ ) specimen, Westphal-MMD11 (Chapman et al. 2000). Baker et al. (2004) demonstrated through sensitive CO(4-3) observations that it is not a typical member of the submm galaxy population (c.f., Greve et al. 2005). While one possibility is that the dust in LBGs is significantly hotter than typical submm galaxies (making them harder to detect at  $850\mu\text{m}$ ), similar to the radio-selected  $z \sim 2$  ULIRGs in Chapman et al. (2004a) and Casey et al. (2009), it would be surprising if this characterized the bulk of the LBG population since nothing about their properties suggests they would have hotter dust on average than other classes of star forming galaxies. Several LBGs have been detected at  $24\mu\text{m}$  using *Spitzer* (Huang et al. 2005, Reddy et al. 2006), although it is not yet clear whether this excess  $24\mu\text{m}$  emission comes from a truly high SFR, intricacies in the aromatic dust features, or a power law AGN component. Deep submm observations comparable to those presented in this work will be the ultimate diagnostic for star formation in high- $z$  LBGs.

Identified as a LBG in the surveys of Steidel et al. (2003), Westphal-MM8 has from its rest-frame UV spectrum an exceptionally large SFR ( $> 100 \text{ M}_{\odot} \text{ yr}^{-1}$ , after correction for dust extinction). However, the infrared colors and overall properties do not single this object out as unusual for the population in any other respects. In this letter we present



**Figure 1.** SCUBA 850 $\mu$ m and 450 $\mu$ m images of the region surrounding the LBGs MM8, MMD11. The field is 4.5'  $\times$  4.5', where the 450 $\mu$ m array covers a slightly smaller area than the 850 $\mu$ m, but with 191 (versus 37) bolometers. The two detected LBGs, MM8 and MMD11 are circled in red, as is a serendipitously detected SMG in the deep map surrounding MM8.

deep confusion limited submm observations of MM8, probing the emission from the dusty component. Throughout we assume a cosmology with  $h = 0.7$ ,  $\Omega_{\Lambda} = 0.72$ ,  $\Omega_M = 0.28$  (e.g., Hinshaw et al. 2008).

## 2 OBSERVATIONS AND ANALYSIS

Westphal-MM8 was observed with the Submillimetre Common-User Bolometer Array (SCUBA – Holland et al. 1999) on the James Clerk Maxwell Telescope (JCMT) on Mauna Kea, Hawaii. The observations presented here are the combination of the original observation presented in Chapman et al. (2000) (5.4 ks on source) and two archival observation (6.7 ks and 6.0 ks on source respectively). The combined observation represents two complete 8 hr JCMT shifts centered on this single LBG, and reaches a sensitivity level even deeper than the Hughes et al. (1998) SCUBA map of the Hubble Deep Field.

All observations were taken in the standard PHOTOMETRY mode of SCUBA, divided into  $\sim 30$  min scans with azimuthal chop angle to minimize atmospheric gradients, a chop frequency of 7.8125 Hz, and a throw of either 40'' or 45''. All observations were taken between 1998 and 2000 under superb submm observing conditions. The sky rotation over the fixed Nasmyth array coordinate resulted in all angles on the sky being covered by the chop throw (Fig. 1). We make no attempt to fold in the few times when the source actually crossed another bolometer in an offbeam.

Pointing was checked hourly on blazars and sky-dips were performed routinely to measure the atmospheric opacity directly. The RMS pointing errors were below 2 arcsec, while the average atmospheric zenith opacities at 450  $\mu$ m and 850  $\mu$ m were 1.7 and 0.20 respectively. The data were reduced using the Starlink package SURF (Scuba User Reduction Facility, Jenness et al. 1998). Spikes were first carefully rejected from the data, followed by correction for at-

mospheric opacity and sky subtraction using the median of all the array pixels, except for obviously bad pixels and the source pixels. The data were then calibrated against standard planetary and compact H II region sources, observed during the same nights.

All the scans on source were combined with inverse variance weighting. The final signal measured is  $1.98 \pm 0.48$  mJy at 850  $\mu$ m, with no significant detection at 450  $\mu$ m. Dividing the dataset in half shows a similar detection significance in each half, increasing our confidence that a true detection has been achieved (that the final result is not the bias of any small part of the dataset). The MM8 observation is adjacent to three other shorter exposures of LBGs, included the detected MMD11 described above and two others showing insignificant but positive flux density. We combine all these observations into a single map for illustration and comparison (Fig. 1).

At such faint SCUBA flux levels, we must be cautious of both confusion noise and interloping source effects on our signal. The probability that a random galaxy lies within the beam is given by  $P = 1 - \exp(-\pi n \theta^2)$ , where  $n(> S)$  is the cumulative surface density for the population in question, and  $\theta$  is the beam radius. For a flux density of 1.9 mJy the source counts are about 5000 per square degree (e.g. Blain et al. 1999), and so  $P \simeq 4\%$  per pointing. Although nine high-SFR LBG candidates were observed in the original Chapman et al. (2000) sample, the average sensitivity reached was only 1.2 mJy RMS. Thus although the chance that at least one of these observations is contaminated by a 1.9 mJy source is then  $\sim 27$  per cent, the MM8 observation is the only one for which any significant flux would have been measured. In addition, as we shall demonstrate below, the potential *interloper* is highly likely to be drawn from the high-SFR LBG population in the first place, making it even more unlikely that some optically faint source is in fact contributing this submm flux.

The issue of confusion noise (Scheuer 1957, Condon

1974) considers the fluctuations due to undetected sources which contribute to our error bars. A full discussion of the effects of confusion on deep SCUBA photometry observations can be found in Chapman et al. (2000). Blain et al. (1998) quote a value of 0.44 mJy for the variance due to confusion, derived from their source counts. This is comparable to our measured RMS for MM8, and since the errors add in quadrature, this is the dominant source of noise. The actual flux of MM8 may therefore be skewed slightly brighter than our measured value. Again, however, we note that the contribution to the confusion noise from the 1-2 mJy submm sources is likely to arise from the LBG population itself, and thus by pointing at a known high-SFR LBG, we have somewhat reduced the likelihood of confusion bias. For the other literature, unlensed LBG sources considered in this letter, confusion noise is sub-dominant and does not significantly affect our result.

We also searched for additional submm sources significantly detected in the deep maps. We detect one additional SMG in the outer region of the 850 $\mu$ m map ( $S_{850\mu\text{m}} = 5.8 \pm 1.4$  mJy), which is marginally detected at 450 $\mu$ m. While the outer regions of the map are not as deep as the central point, at  $\sigma = 1.4$  mJy, it remains one of the deepest maps ever taken by SCUBA, and it is statistically expected that we would detect one source brighter than 5 mJy (e.g., Coppin et al. 2008). None of the LBGs or the new SMG presented in this region are detected in the radio (Ivison et al. 2007) or Xray (Nandra et al. 2007), and there is no *Spitzer* data covering this area.

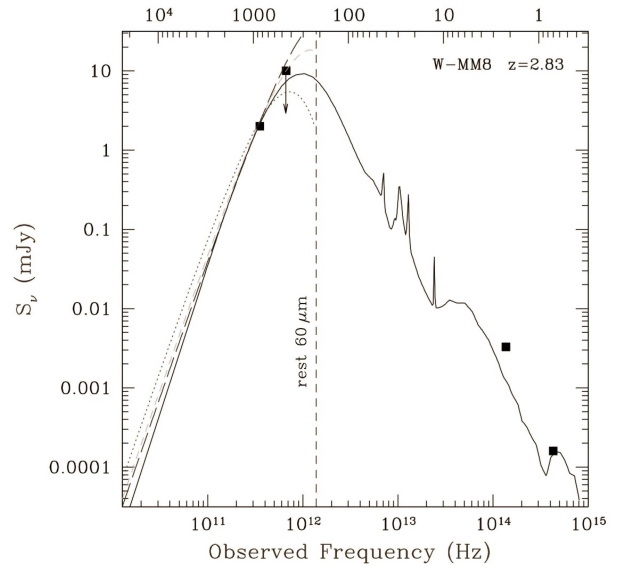
### 3 RESULTS

#### 3.1 MM8 Luminosity and Dust Content

Figure 2 presents the extant data of MM8 (optical data points from Shapley et al. 2001), including the new SCUBA data discussed in § 2. Also plotted is the spectral energy distribution (SED) of a possible local analog to MM8, the starforming galaxy M82. Although still a relatively extreme object, MM8 represents the faintest galaxy ever detected with SCUBA, comparable to the faintest object in the Hubble Deep Field SCUBA observation of Hughes et al. (1998), HDF850.5 ( $S_{850\mu\text{m}} = 2.1 \pm 0.5$  mJy), or the ultra-deep Abell2218 SCUBA map of Knudsen et al. (2006), SMM J163602.6+661255 with  $S_{850\mu\text{m}} = 2.8 \pm 0.6$  mJy. This fact emphasizes the difficulty in detecting more typical star-forming galaxies at high redshift in the submm wavelengths with present facilities and achievable sensitivities.

Simply scaling the observed submm photometry from that of Arp220 implies that MM8 has an infrared luminosity of  $L_{\text{IR}} \sim 2 \times 10^{12} h_{70}^{-2} L_{\odot}$ , placing it in the ultra-luminous class of infrared galaxies (Sanders & Mirabel 1996). MM8 displays no evidence of gravitational lensing, appearing point-like in the optical at a PSF-scale  $\sim 0''.7$ . Again scaling from the Arp220 model, the resulting dust mass in MM8 is  $\sim 3 \times 10^6 M_{\odot}$ . Without more data over the SED of MM8, this value possesses a significant uncertainty, but does indicate that MM8 harbours a large quantity of dusty material.

In Table 1, we present measured and predicted 850 $\mu$ m flux densities along with the UV-derived SFR for the submm-detected LBGs, MM8 and MMD11, and the lensed



**Figure 2.** The spectral energy distributions of MM8 ( $z=2.83$ ) as compared to a representative local starforming galaxy, M82 (solid line). The top axis shows the observed frame wavelength in microns. Also plotted in dashed lines are modified blackbody spectra for emissivity  $\beta = 1.5$  and  $T_d = 30, 50$ , and  $70$  K (dashed lines), normalized to the  $850 \mu\text{m}$  point. For nearby galaxies, the IRAS  $60 \mu\text{m}$  band has typically been used to estimate SFRs. We have marked the location of this band (in the rest-frame) with a vertical dotted line for both objects, as an indication of the extrapolation used in this study relative to nearby objects. Optical  $R$  and  $K$ -band photometry comes from Shapley et al. (2001).

LBGs with submm or CO detections are available. Of the lensed LBGs, it is noteworthy that SMMJ16359 and MS0451-a were discovered on their submm-properties and not through the LBG selection criterion. For the two cases where  $S_{850}$  was estimated from the CO luminosity, an additional uncertainty of the order 50% is likely, as measured directly for the SCUBA-bright population in Greve et al. (2005). The UV-predicted  $S_{850}$  is highly dependent on the dust parameters adopted. We have used the empirical dust curve for M82 which appears to accurately predict  $S_{850}$  for MM8, whereas a combination of different dust emissivity ( $\beta$ ) and dust temperature would result in significant changes to the predicted submm emission. The uncertainty in this estimate based on the estimated local and high- $z$  dust temperature distributions (e.g., Blain et al. 2004) is  $\sim 0.3$  dex.

#### 3.2 Implications for the faint submm sources

A correlation is expected between the rest frame UV continuum and the far-IR emission for starforming galaxies, since much of the UV radiation emitted by hot O- and B-type stars is absorbed by dust and re-radiated at far-IR wavelengths in the form of a modified black body. Meurer et al. (1999) have shown this to be the case for local starform-

**Table 1.** Predicted and measured (intrinsic) submm flux densities for high SFR Lyman break galaxies. We give the galaxy designation, RA/Dec, redshift, observed 850  $\mu$ m flux density, *R*-band magnitude, the SFR derived from the UV-corrected flux, and the 850  $\mu$ m flux density predicted from the UV data.

Galaxy	RA (J2000)	Dec (J2000)	<i>z</i>	$S_{850}$ <sup>a</sup> (mJy)	$R_{AB}$ (mag)	SFR <sub>UV-corr</sub> <sup>b</sup> ( $M_{\odot} \text{ yr}^{-1}$ )	$S_{850-UV}$ <sup>c</sup> (mJy)
<b>Unlensed LBGs observed in the SCUBA map</b>							
West-MM8 <sup>e</sup>	14:18:23.90	+52:23:07.7	2.829	$1.98 \pm 0.48$	24.13	$175 \pm 164$	$1.5 \pm 1.1$
West-MMD11	14:18:09.71	+52:22:08.5	2.979	$5.51 \pm 1.38$	24.05	$173 \pm 95$	$1.2 \pm 0.6$
<b>serendipitous SMG discovered in the SCUBA map</b>							
West-SMG1	14:18:29.57	+52:22:54.4	—	$5.83 \pm 1.39$	—	—	—
<b>Lensed LBGs from the literature<sup>d</sup></b>							
CosmicEye	21:35:12.73	-01:01:42.9	3.074	0.75	20.3	100	2.0
MS0451-a	04:54:10.90	-03:01:07.0	2.911	0.40	22.9	10	0.2
cB58	15:14:22.27	+36:36:25.2	2.723	0.39	20.3	24	0.6
SMM J16359	16:35:54.50	+66:12:31.0	2.517	0.65	23.0	9	0.3
Cosmic Horseshoe	11:48:33.15	+19:30:03.5	2.379	2.03	19.0	80	2.3

<sup>a</sup>  $S_{850}$  either measured directly or inferred from CO detections (the latter described in <sup>d</sup>).

<sup>b</sup> Calzetti (1997) attenuation curve corrected, taking into account Monte Carlo simulations of the photometric errors. Simple RMS errors are quoted, while in fact the distributions are skewed (Adelberger & Steidel 2000).

<sup>c</sup> Predicted from the UV colours; see Chapman et al. 2000 and Adelberger & Steidel 2000 for detailed discussion.

<sup>d</sup> Properties derived for lensed sources referenced as follows: Cosmic Eye (Coppin et al. 2007), MS0451-a (Chapman et al. 2002, Borys et al. 2004), cB58 (Baker et al. 2004), SMM J16359 (Kneib et al. 2005 – where we have quoted their central pointing between the multiply imaged galaxy), Cosmic Horseshoe (Belokurov et al. 2007, Casey et al. in prep). In two cases where 850  $\mu$ m measurements were not obtained (Cosmic Eye and Cosmic Horseshoe) the 850  $\mu$ m flux was inferred from the CO gas through the relation in Greve et al. (2005), where an additional uncertainty of  $\sim 50\%$  is introduced by the scatter in SCUBA-bright galaxy properties.

<sup>e</sup> The redshift of MM8 appears in Shapley et al. (2001) as 2.829 (as quoted here), while  $z = 2.839$  (in a table) and  $z = 2.841$  (in a figure) are given in Steidel et al. (2003).

ing galaxies with bolometric luminosities  $L \sim 10^{11} L_{\odot}$ , with a factor of two scatter in the relation. However, such a relation can only be expected to hold if the bulk of the detected UV and far-IR radiation are emitted from the same location in the galaxy. Related is the problem of vastly different optical depth effects in the two wavelength regimes. These issues are verifiable in local galaxies but difficult in high redshift objects, where typically only the integrated emission is known. For extremely luminous local starburst galaxies such as Arp220 ( $L \sim 10^{13} L_{\odot}$ ), the dominant UV and far-IR components are observed in different spatial locations, and the integrated UV to far-IR ratio lies significantly above the Meurer et al. (1999) correlation (see Goldader et al. 2005). The UV/far-IR relation must be taken as unreliable for such hyper-luminous infrared galaxies. However, objects like MM8 lie in the interim luminosity regime ( $L \sim 10^{12} L_{\odot}$ ), for which Reddy et al. (2006) have suggested the UV/far-IR relation appears to hold on average based on mid-IR, radio, and X-ray stacking observations.

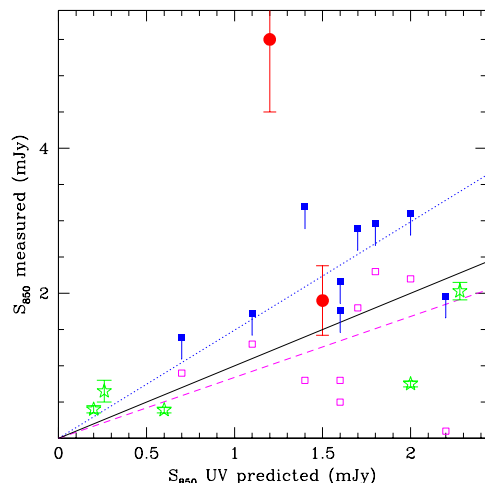
In Figure 3, we present the measured (or intrinsic)  $S_{850}$  versus UV-predicted  $S_{850}$  for the LBG sample, depicting the  $x = y$  relationship. The two detected LBGs (WestphalMMD11 and MM8) are highlighted against Bayesian 95% confidence upper limits for literature sources. We also show the explicit measurement limits for these LBGs as  $S_{850} + 1\sigma \times rms$  (mJy). Two fits are made to unlensed LBGs, one using the Bayesian limits, and one using the  $S_{850} + 1\sigma$  points. The fits are constrained to pass through the origin. In both cases we exclude MMD11 since its submm luminosity places it in the class of hyper-luminous objects (Sanders & Mirabel 1996), and as such its UV/farIR relation is particularly suspect. The five lensed LBGs with

submm measurements are reasonably described by the fit to the  $S_{850} + 1\sigma$  data, suggesting the Bayesian limits are likely a conservative estimate of the relation. The relation ( $S_{850, \text{measured}} = 0.8 \times S_{850, \text{predicted}}$ ) is therefore proposed as a high redshift UV/far-IR fiducial for estimation of the LBG contributions to the submm source count.

## 4 DISCUSSION

Most of the 850  $\mu$ m background appears to be produced by objects with  $S_{850} \sim 1$  mJy (e.g., Smail et al. 2002), and the data in this paper are consistent with the idea that these dusty 1 mJy sources which dominate the background have UV properties similar to LBGs. With our derived UV/far-IR relation at high redshift, we calculate a 1-2 mJy surface density of  $3600 \text{ deg}^{-2}$  for LBGs with expected  $\text{SFR} > 100 M_{\odot} \text{ yr}^{-1}$  over the redshift range  $z = 1.5-3.5$  (using the Reddy et al. 2008 luminosity function). This represents  $> 70\%$  of the measured 1-2 mJy submm source counts (cf. Blain et al. 1999, Knudsen et al. 2006), and as such suggests that optical surveys typically uncover the sources which begin to dominate the fainter submm source counts. If all UV-selected  $z \sim 3$  with  $\text{SFRs} \sim 100 M_{\odot} \text{ yr}^{-1}$  galaxies are as dusty as the present analysis suggests, then UV-selected populations probably produce the bulk of the 850  $\mu$ m background (see also Adelberger & Steidel 2000).

However, the specific galaxies which dominate the  $S_{850} \sim 1$  mJy counts is still a debated issue, where other investigations propose significant contributions from various classes of galaxies selected at different redshift intervals (e.g. Wehner et al. 2002, Webb et al. 2003, Knudsen et al.



**Figure 3.** The measured  $S_{850}$  versus UV-predicted  $S_{850}$  for  $z \sim 3$  LBGs, a solid line depicting the direct  $x = y$  relationship. The two detected LBGs (MMD11 and MM8) are shown with large red circles. The solid blue squares represent Bayesian 95% upper limits to the LBGs presented in Chapman et al. (2000), while the open squares (magenta) show the measured  $S_{850} + 1\sigma$  (mJy) points, where  $+1\sigma$  is the minimum offset to bring all values positive. The blue (dotted) line represents a fit to the Bayesian 95% upper limits constrained to pass through the point (0,0), including the detection of MM8, but excluding the extreme object Westphal MMD11. The magenta line (dashed) is a fit to the  $S_{850} + 1\sigma$  points, again excluding Westphal MMD11. We take this relation as our high redshift UV/far-IR fiducial for estimation of the LBG contributions to the submm source count and far-IR background. Five lensed LBGs with submm measurements are also shown as stars. These LBGs reasonably agree with a one-to-one correspondence of predicted/measured  $850\mu\text{m}$  flux.

2005, Wang et al. 2006). We note firstly that many high redshift galaxies selected at longer wavelengths do have colours consistent with the LBG selection (e.g., Reddy et al. 2008), including a substantial fraction of the hyper-luminous SMGs (Chapman et al. 2005), and thus one should expect an overlap between the different galaxy classes that are estimated to contribute significantly. The second obvious problem with these analyses is the large ( $\sim 15''$ ) confusion limited beam-sizes of submm/mm measurements, allowing the galaxies of different types which may well cluster together to be collectively measured in the same  $850\mu\text{m}$  beam. Of note is the low average  $850\mu\text{m}$  flux for LBGs inferred by Chapman et al. (2000), Peacock et al. (2000), and Webb et al. (2003),  $< 1$  mJy. Individual objects in these samples likely have SFRs substantially lower than the UV-inferred SFR due to the photometric uncertainties described in the introduction. Finally, we note the indirect estimates of the SFR. Without direct constraint of the far-IR peak for high redshift, luminous galaxies, there remains substantial uncertainty in estimating how any particular population contributes to the far-IR backgrounds.

The discovery, confirmation, and full characterization of  $z \sim 2 - 2.5$  evolved galaxies with no ongoing star formation (e.g., Kriek et al. 2008, van Dokkum et al. 2008) demands a sizable progenitor population to rapidly form the stars at  $z > 3$ . The submm-luminous galaxy population ( $S_{850\mu\text{m}} >$

5mJy) for the most part cannot fulfill this role as they lie predominantly at  $z \sim 2$  (e.g., Chapman et al. 2005, Ivison et al. 2007, Clements et al. 2008), coeval with this old evolved population. These submm-selected galaxies have a rapidly declining luminosity function beyond  $z > 2.5$ , dropping in volume density over  $2\times$  from  $z = 2-3$ , and likely a factor  $\sim 10$  from  $z = 2-4$  (Chapman et al. 2005, Pope et al. 2006). However galaxies with  $S_{850\mu\text{m}} \sim 1-2$  mJy could remain be numerous at  $z > 3$  (e.g., Adelberger & Steidel 2000) and would still represent an ultra-luminous population.

While we do not extrapolate submm properties explicitly from this single submm detection of a *typical* LBG at  $z \sim 3$ , we state for reference the expected volume density of  $z \sim 3$  LBGs with likely  $S_{850\mu\text{m}} > 1$  mJy (total infrared luminosities  $L_{\text{IR}} > 10^{12} L_{\odot}$ ) from Reddy et al. (2008):  $\Phi \sim 3 \times 10^{-4} h_{0.7}^3 \text{Mpc}^{-3}$ , which is very similar to their estimate for  $z \sim 2$  indicating little redshift evolution. Contrast bright submm-selected galaxies which would only have  $\Phi < 10^{-6} h_{0.7}^3 \text{Mpc}^{-3}$  at  $z \gtrsim 3$  (Chapman et al. 2005).

Measuring the submm fluxes of large samples of known  $z = 2 - 4$  galaxies will be a cornerstone goal of SCUBA2 (Holland et al. 2003), where vast confusion-limited surveys at both  $850\mu\text{m}$  and  $450\mu\text{m}$  will be achieved. This will allow the extension of this study to large samples of galaxies, although the issue of confusion noise will persist at  $850\mu\text{m}$ . As shown in Fig. 2, the limit we achieved for MM8 at  $450\mu\text{m}$  for MM8 is not quite deep enough to discriminate between different dust temperatures (or SED shapes in general). However, the confusion-limited  $450\mu\text{m}$  sensitivities ( $\sim 0.5$  mJy rms) listed in the goals of the deep SCUBA2 Legacy programmes<sup>1</sup> are more than sufficient to completely characterize dust temperature distributions even for  $z > 3$  galaxies, and the reasons for the submm detectability raised in § 1 will become clear. E-MERLIN<sup>2</sup> and E-VLA<sup>3</sup> will also be able to detect these populations directly at 1.4 GHz, and in addition constrain their radio sizes, potentially well in advance of being able to study their sizes directly in the submm with ALMA<sup>4</sup>. Finally, followup of unlensed LBGs (using the IRAM, Plateau de Bure Interferometer) in molecular CO gas has met with four failures and no successes (Baker et al. 2004b, Tacconi et al. 2008). MM8 represents an obvious candidate for CO followup, however based on the current lack of success, it is likely that ALMA will be required for full characterization of these galaxies dominating the submm background.

## 5 CONCLUSIONS

We have presented submm observations of the  $z = 2.83$  LBG MM8, nominally the deepest SCUBA observation ever taken of a distant galaxy. These observations confirm that this LBG has a large star formation rate ( $\sim 200 M_{\odot}/\text{yr}$ ) as indicated by the dust-corrected UV. MM8 is associated with a large quantity of dust, with an inferred infrared luminosity of  $\sim 2 \times 10^{12} h_{70}^{-2} L_{\odot}$ .

Despite the large dust mass, enough of the UV remains

<sup>1</sup> <http://www.jach.hawaii.edu/JCMT/surveys/Cosmology.html>

<sup>2</sup> <http://www.merlin.ac.uk/e-merlin>

<sup>3</sup> <http://www.aoc.nrao.edu/evla>

<sup>4</sup> <http://almaobservatory.org>



in view to provide a clear indication of the expected submm flux. This contrasts with typical submm-luminous galaxies where high resolution radio and mm-interferometry (Chapman et al. 2004b, Tacconi et al. 2006, 2008) have demonstrated that the bolometrically luminous region can lie significantly offset (several kpc) from UV-luminous regions. This suggests that for less luminous  $z \sim 3$  galaxies like MM8, the dust distribution may not hinder the UV/far-IR relation to the same extent. The observations presented here also suggest that individual LBGs from the sample of Chapman et al. (2000) could be similar in submm properties to MM8 ( $\sim 1\text{--}2\text{ mJy}$ ), and SCUBA2 surveys may regularly detect these galaxies in its confusion limited wide field surveys.

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